# U. S. NAVAL SUBMARINE MEDICAL CENTER

**Submarine Base, Groton, Conn.**

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## MAXIMUM PERMISSIBLE LIMITS OF CONTAMINANTS FOR DIVERS' BREATHING GAS:

An Overview

by

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit M4306.02-2110B.02



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## SUMMARY PAGE

### THE PROBLEM

To summarize the steps in the chain of biomedical investigation of contaminant toxicity and pertinent pitfalls associated with them, -- time frame extrapolations, establishment of limits applicable to hyperbaric environments and relevance of partial pressure increases and the possible synergism or antagonism among multiple contaminants.

### FINDINGS

It is established that flexible threshold limits are desirable, limits that permit and require adjustment to the time, depth and mission profile of the operation.

### APPLICATION

The discussion presented in this paper will be of interest to all Naval personnel concerned with the safety and efficiency of diving operations of all varieties. The desirability of having medical personnel who are cognizant of operational conditions participate in establishment of appropriate toxicity limits is stressed.

### ADMINISTRATIVE INFORMATION

This report was prepared as a preliminary to investigation of Bureau of Medicine and Surgery Research Work Unit M4306.02-2111B - Physiological Effects of Saturation Diving. The present report is No. 2 on that Work Unit. The manuscript was approved for publication on 12 June 1970 and designated as Submarine Medical Research Laboratory Report No. 631. This material is to be presented to a Symposium on Purity Standards for Divers, at Battelle Memorial Institute, Columbus, O., 9-10 July 1970.

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## ABSTRACT

A valid end-product of Navy biomedical research is the establishment of limits of contamination of breathing gas tolerable to Naval personnel in operational settings. Customary steps in the determination of these limits include exposure of laboratory animals to the contaminant followed by observation of patterns of morbidity and mortality in those animals. This data is then extrapolated to humans under exposure conditions that may or may not be similar to those of the laboratory experiment. In addition to animal-human, and time-frame extrapolations, establishment of limits applicable to the hyperbaric environments must also consider the relevance of partial pressure increase and the possible synergism or antagonism among multiple contaminants. This paper elaborates on these steps in the chain of biomedical investigation of contaminant toxicity and the pertinent pitfalls associated with them.

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# MAXIMUM PERMISSIBLE LIMITS OF CONTAMINANTS FOR DIVERS' BREATHING GAS:

## AN OVERVIEW

A valid end-product of Navy biomedical research is the establishment of limits of contamination of breathing gas tolerable to Naval personnel in operational settings. Clues as to proper approach in establishing environmental hazard limits are available from observations of the industrial hygionist, radiation biologist, and more recently the ecologist concerned with community air and water pollution. Until quite recently the impact of these groups upon the diving community has been small and remote. Pure air for the diver was determined by how it smelled, and in the rare instance of gross contamination, was announced by rapid onset of incapacity of the user-victim. Currently the operational opportunities inherent in deeper dives of long duration are recognized. There is both increasing sophistication of equipment provided the diver and increasing complexity of underwater assignments. These factors have demanded that attention be turned toward providing the diver with breathing gas that maximizes his ability to get the task completed safely and efficiently and minimizes acute or long term untoward effects.

Establishment of threshold limits for underwater work is beset by a number of difficulties. Not least among these is the large variety of missions and tasks that the Navy diver may be called upon to perform. These range all the way from the barely submerged individual performing a hull inspection or a screw change, to the aquanaut saturated in the deep ocean for a multiday assignment. Somewhere between is the untethered UDT swimmer and the hard hat diver tethered from the surface at moderate depths for moderate durations. Each group has its own individual problems and unique needs. It is a point to be emphasized that these problems and needs often require as part of their solution individual adjustment of the threshold limit.

One of the controlling considerations, not unique to the diver, is the relative importance of acute or long term effects. If exposures are short and infrequent and the cumulative effects minimal, the threshold for the acute effects of the particular toxin will be of prime importance. If on the other hand exposures are of long duration, frequently repeated, and the toxic effects are cumulative, a much lower threshold for the chronic effects is generally significant. The problems thus generated are twofold. First, the long latent period often present prior to the first manifestations of the effect may delay recognition of the cause and effect relationship of the contaminant to the disease. Secondly, the low thresholds frequently associated with chronic effects may make measurement of the level of contamination difficult under operating conditions.

Another important consideration in determining any threshold limit is that of recovery period and the associated concept of cumulative damage. In the development of threshold limits applicable to nuclear submarine operations, limits for an eight hour day-forty hour week, common in industrial medical practice, were not applicable to the 24 hour per day-sixty to ninety day exposures common to the submarine operations. The very important biological consideration is that continuous exposures do not permit recovery of tissue and organ insult. Damage accumulates that would in other circumstances be repaired by homeostatic processes. Compensation must come in part from lowering the tolerable level of contaminant.

A special case in which understanding of recovery period phenomena is important is in the consideration of an acute emergency exposure limit. Such limits might be particularly applicable for instance in the case of submarine escape operations. Here the need to exceed general limits is great, duration of exposure is small, and frequent repetition unlikely.

An understanding of the pathways of metabolism of the contaminant is as important in establishing limits for underwater work as in classical toxicology. In many cases the influence of hyperbaric or aquatic environment on these pathways is not well defined. In addition, the diver often brings to the underwater world a body burden of a contaminant acquired from the generally polluted terrestrial environment from which he enters the water. The added effect of this body burden must also be considered in the final analysis of the threshold limit.

In any general discussion of threshold limits the relationship of the limit to "natural exposure" becomes important. There are recognized environmental hazards to which all individuals are subject. Some of these are indeed above the threshold for biologic damage. Commonly cited examples include bombardment by cosmic radiation from outer space, inhalation of air polluted by congested traffic and undisciplined industry, and ingestion of water with high fluoride content in some geographic areas. These "experiments of nature" not only provide an opportunity to observe the effect of an agent on a large population sample but also provide a platform for limits applicable to a particular operation. Relevant analyses applicable to divers breathing gas might include the levels of inhaled breathing gas pollution to which the city dweller and the cigarette smoker are exposed.

A question to be raised at this point is in regard to what aspect of human physiology the threshold is related. To discuss a threshold limit concept in detail one must soon come to a consideration of target organs. For each contaminant under consideration it must be decided what adverse effect is the limiting factor. In general the categories include:

a. generalized systemic effects

b. local effects

c. central nervous system effects

d. effects on the special senses

The final established limit might be arrived at by a weighting of all of these factors, selection of the one first affected adversely, or selection of the one most directly related to impairment of the task or mission to be performed.

A common practice in establishing limits is to expose various laboratory animals to varying concentrations of the contaminant for graduated periods of time, observe any physiological and pathological effects, and extrapolate from these the levels that will cause similar effects in man. As a first approximation, there is no question about this being a useful and valuable approach. There is an elementary truth, however, which is sometimes overlooked. It is the qualitative and quantitative differences between man and laboratory animals. Direct extrapolation in many cases is misleading. Accordingly, reliance solely on the toxicology laboratory is hazardous. Complementary approaches include the use of epidemiological and physiological techniques for direct observation of man. and evaluation by biomedical personnel familiar with the operational setting.

It is now possible to identify a number of problems in establishing limits for hyperbaric and underwater environments that are unique to these environments. First, there is the frequent inability to separate the diver immediately from the underwater environment once the limits of a no decompression dive are exceeded. Under these conditions back up systems of breathing gas or additional caution in establishing sufficiently low limits for contaminants would seem well advised. Secondly, the role of altered partial pressure as opposed to concentration of contaminant gases must be considered. For those contaminants that exert systemic effects and enter the body as a result pressure gradients between blood alveoli the partial pressure effect appear to be an important one. For those gases which are toxic by reason of a topical irritant effect and, of course, for all non-gaseous atmospheric contaminants, the issue of partial pressure is probably irrelevant. The next unique aspect of the hyperbaric environment is the influence of altered levels of oxygen and carbon dioxide on the behavior of the contaminant. Because of their metabolic and physiologic activity there is the potential for either synergistic or antagonistic effects with the contaminant. The direction of the reaction is not always predictable prior to observation in a simulated environment. Lastly, the hyperbaric environment, with frequent use of artificial gas mixtures, requires adaptation of respiratory mechanics to new gas density and viscosity levels. Preliminary work suggests alteration of pulmonary ventilation and diffusion on exposure to high pressure. This in turn implicates contaminant transport within the lung and its transfer to the vascular space. The ability to accurately predict the magnitude and direction of these alterations requires additional research.

In retrospect, it has not been the intention of this paper to supply answers but rather to group and delineate appropriate questions. There is an obvious need for considerable additional data of both a laboratory/toxicological and epidemiological nature before the biomedical consultant can provide information that is operationally useful. The desirability of having medical personnel who are cognizant of operational conditions participate in establishment of appropriate limits is clear to the author. Lastly, an approach to threshold limits that permits and requires adjustment to the time, depth, and mission profile of the operation would appear highly desirable and should be seriously considered. The Naval Submarine Medical Research Laboratory has unique capabilities in the accomplishment of the necessary foregoing experimentation.

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